Achieving the Potential of Materials Prognosis for Turbine Engines

DARPA Bidders Conference on Materials Prognosis
26 September 2002

J.M. Larsen, S.M. Russ,
A.H. Rosenberger, R. John,
T. Fecke*, and B. Rasmussen

Materials and Manufacturing Directorate

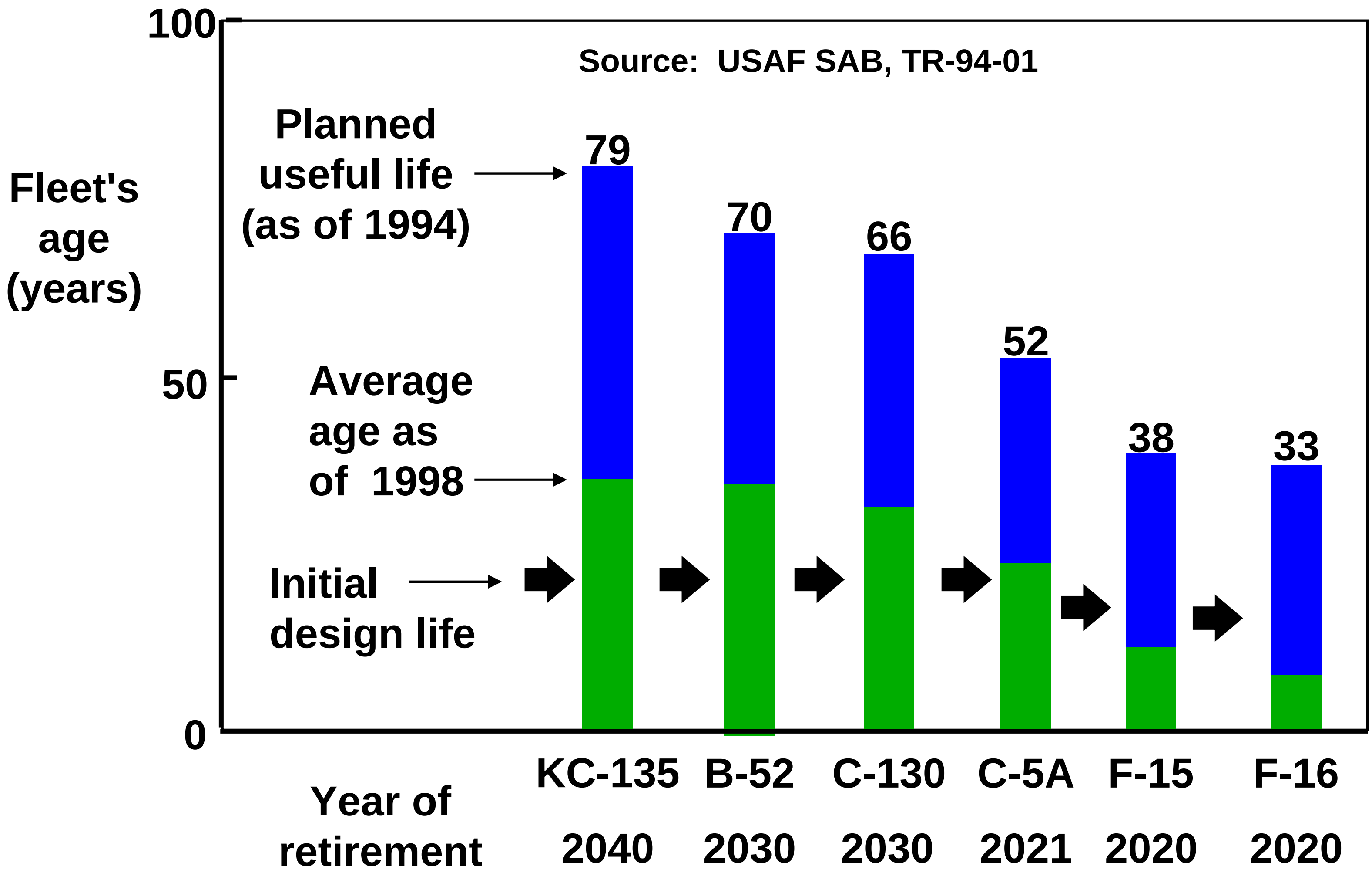
*** Propulsion Directorate**

Air Force Research Laboratory

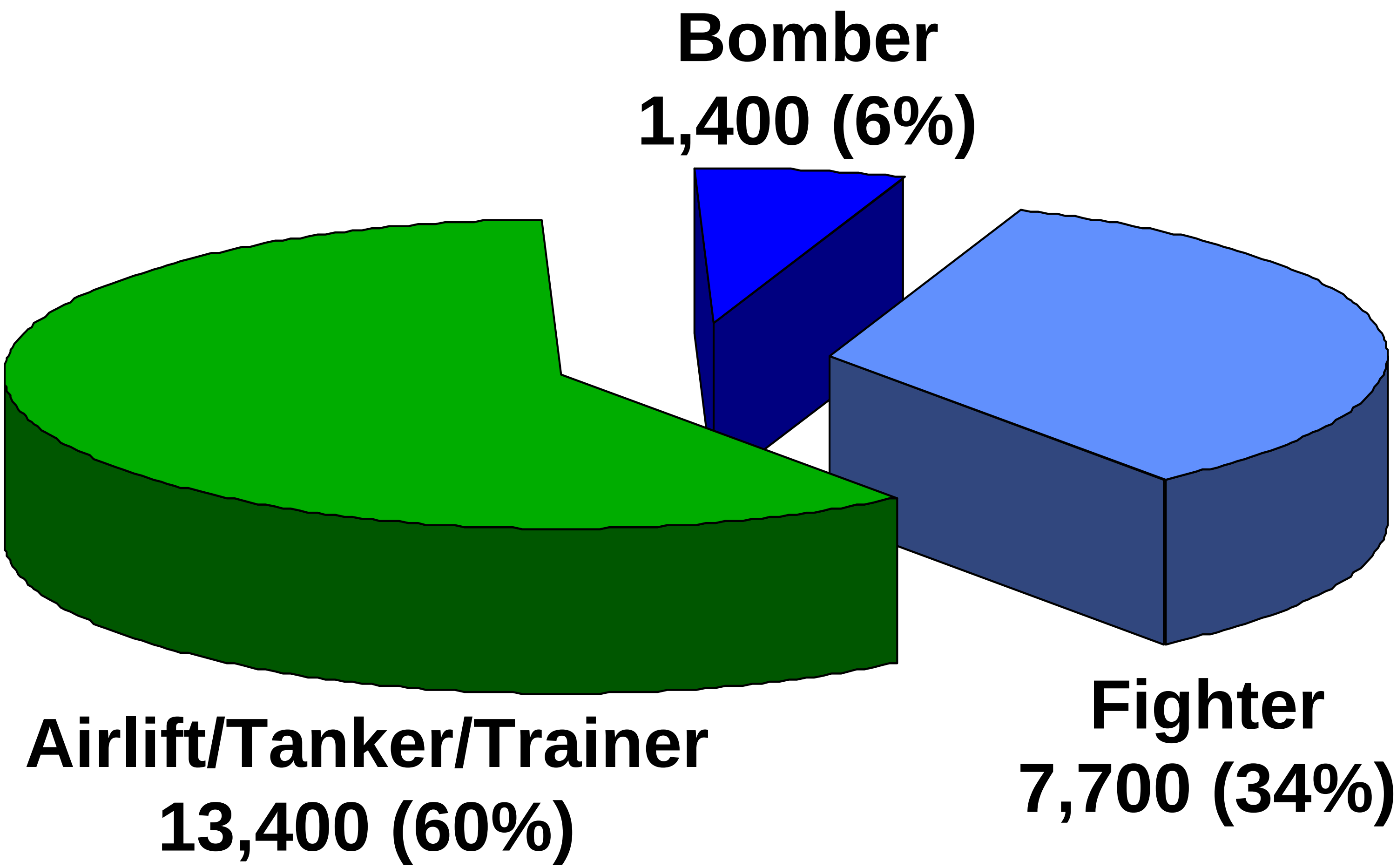
Overview

- **The need for Materials Prognosis of turbine engines**
- **Science and technology outline for Prognosis of Turbine Engine Materials**
- **Future applications and opportunities for technology transition**

Many Aircraft Systems Now In A Second Life



USAF Propulsion Product Group Engine Inventory



~ 22,500 Engines / $33.3B Value

Source: Mr. Timothy Dues, Manager, USAF Propulsion Product Group

Field Maintenance

Reliability Improvements Are Riding on the Backs of our Maintainers with Additional Borescope and Engine Inspections

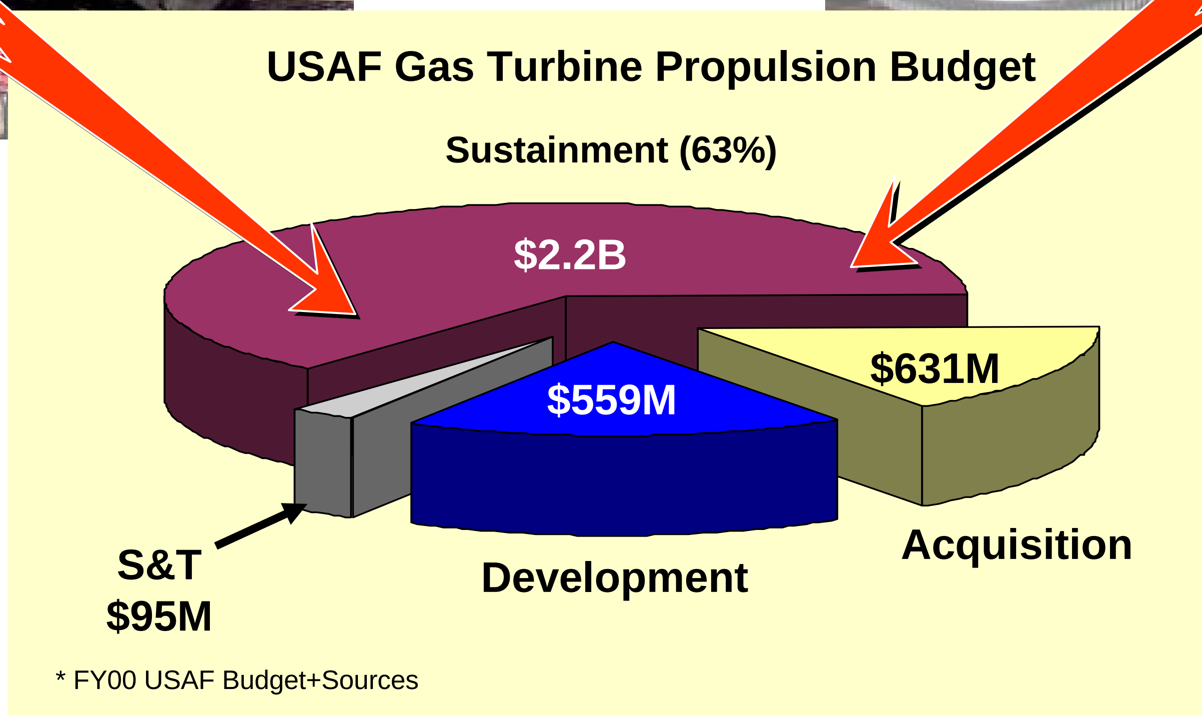
Source: Mr. Timothy Dues, SES
Manager, USAF Propulsion Product Group

Field Maintenance

Those of Us in 72°F Climate-Controlled Offices Have a Responsibility to the Maintainers Who Often Have to Do Their Jobs in 120°F Heat or - 40°F Cold…

Source: Mr. Timothy Dues, SES
USAF Propulsion Product Group

Engine Sustainment Burden

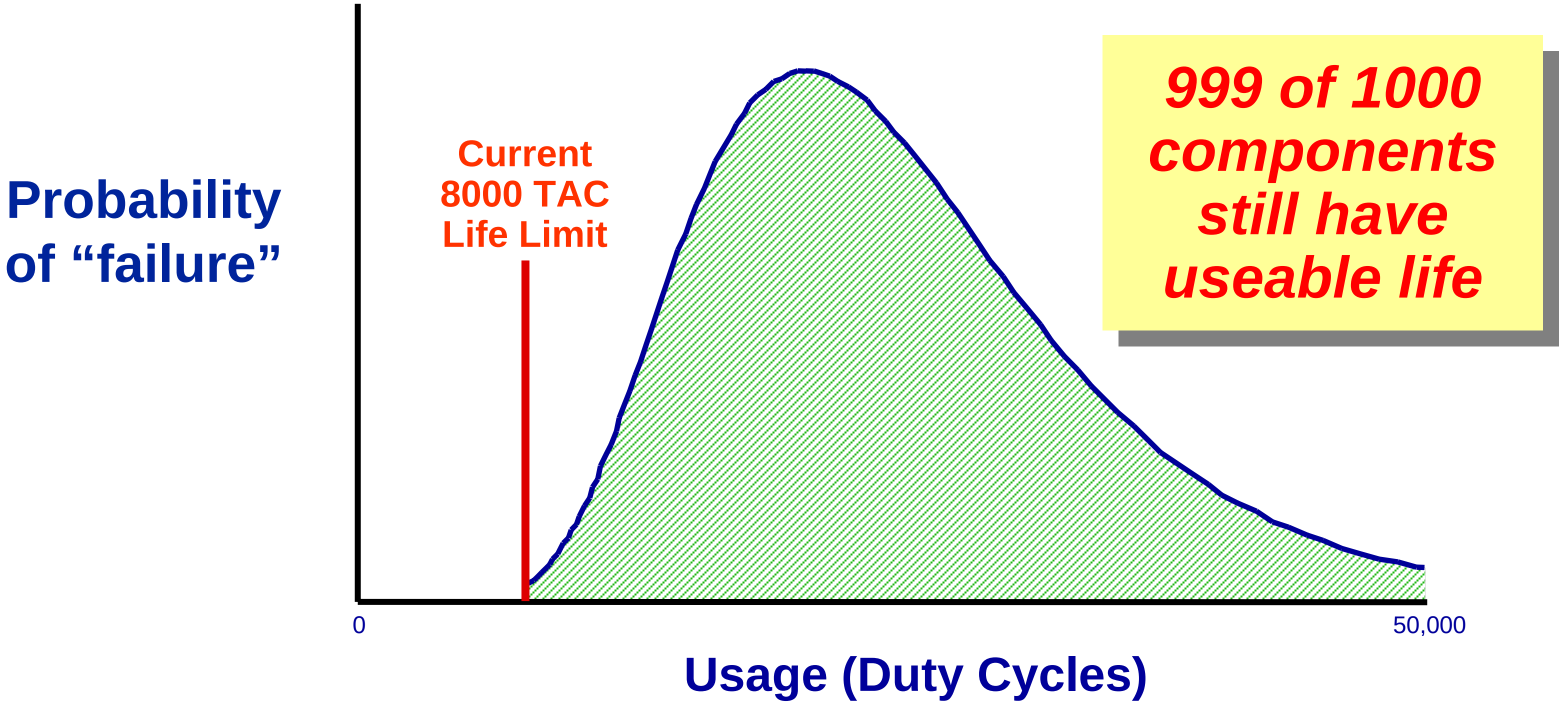


Problem

Turbine engine disks must not fail

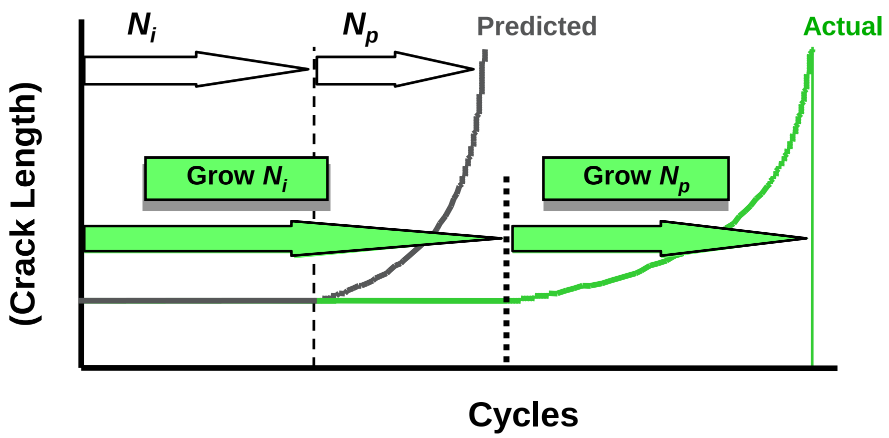
The Problem / Opportunity

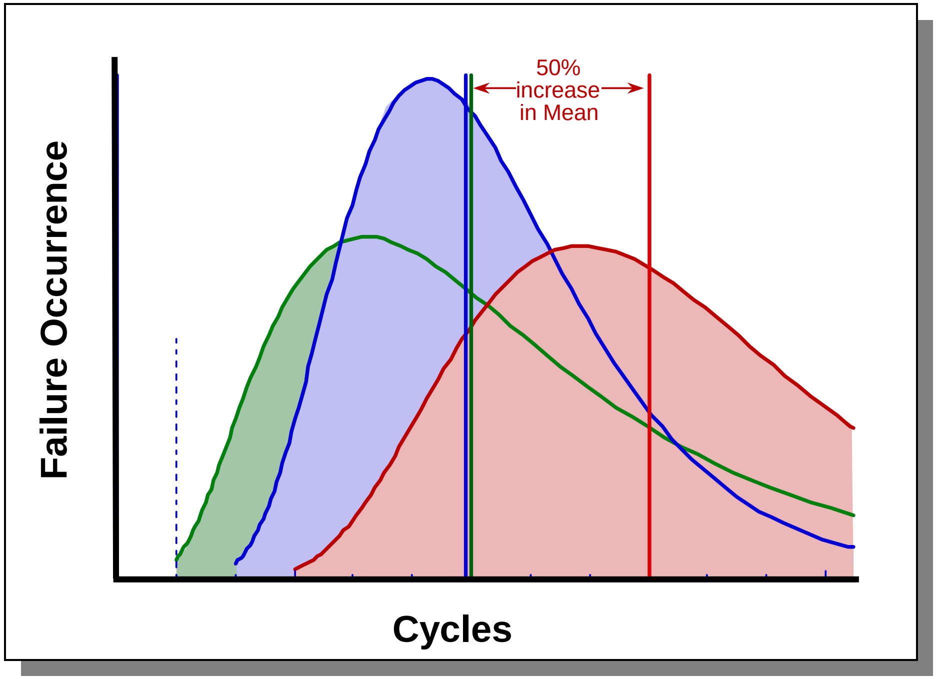
We currently throw away 1000 components
to remove the <u>unknown one</u>
that is <u>theoretically</u> predicted to be in a "failed state"

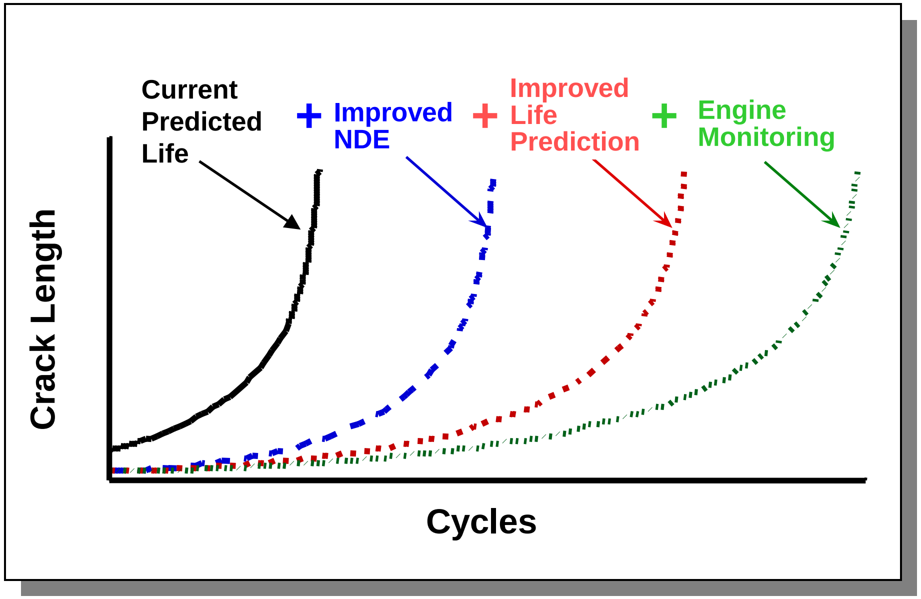


Goal: Recover wasted life <u>without</u> increasing risk

Life Prediction
Potential for Improvements



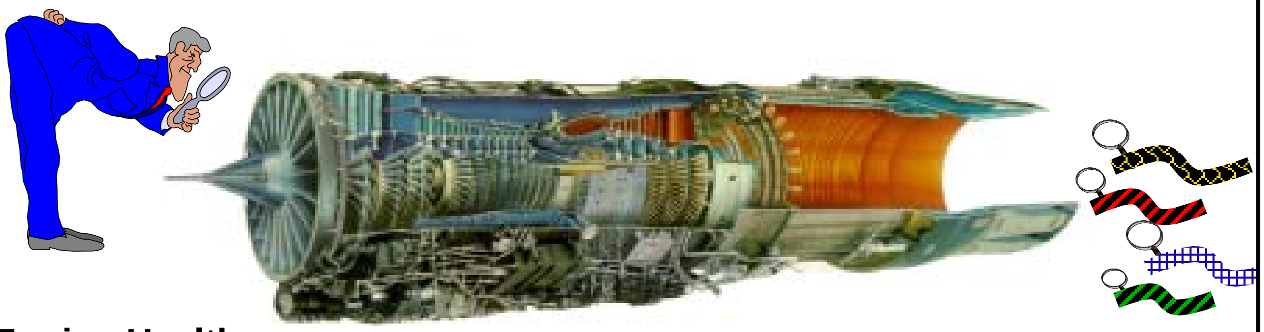




High-Payoff Demonstration Problem: Turbine Engines

- Turbine engines are the primary powerplant for all DoD Services
- Turbine engines represent a crucial, high technology system, that often controls asset readiness
- Turbine engines contain a wide variety of components, and pose a range of levels of difficulty for Materials Damage Prognosis:
  - Disks, blades, vanes, cases, bearings, shafts
  - Range of materials, temperatures, damage modes, and usage and state-awareness sensors
  - Hot flow path is a particularly aggressive environment, requiring improved tools for health assessment and prediction
- Development of Materials Prognosis science and technology offers a major payoff for both the military and commercial sectors:
  - Safety
  - Readiness
  - Asset management
  - Reliability
  - Life extension
  - Reduce maintenance burden

DARPA - Materials Prognosis



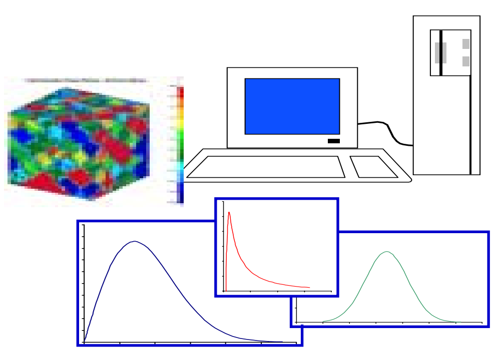
Engine Health Monitoring

Real-time Usage Data

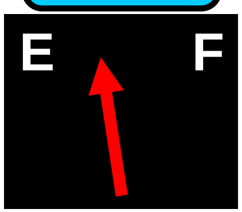
Robotic Inspection “Worms”

Materials Prognosis:
- Physics of failure
- Interrogation techniques
- Feature extraction
- Mission Needs

Physically-Based Probabilistic Life-Prediction Models



Engine Health



Life Gauge

- Life prediction will analyze real-time data, learn, & calculate remaining life
- Sensors will evaluate the state of assets, and mission trends
- Future-mission needs and life calculations will dictate asset allocation

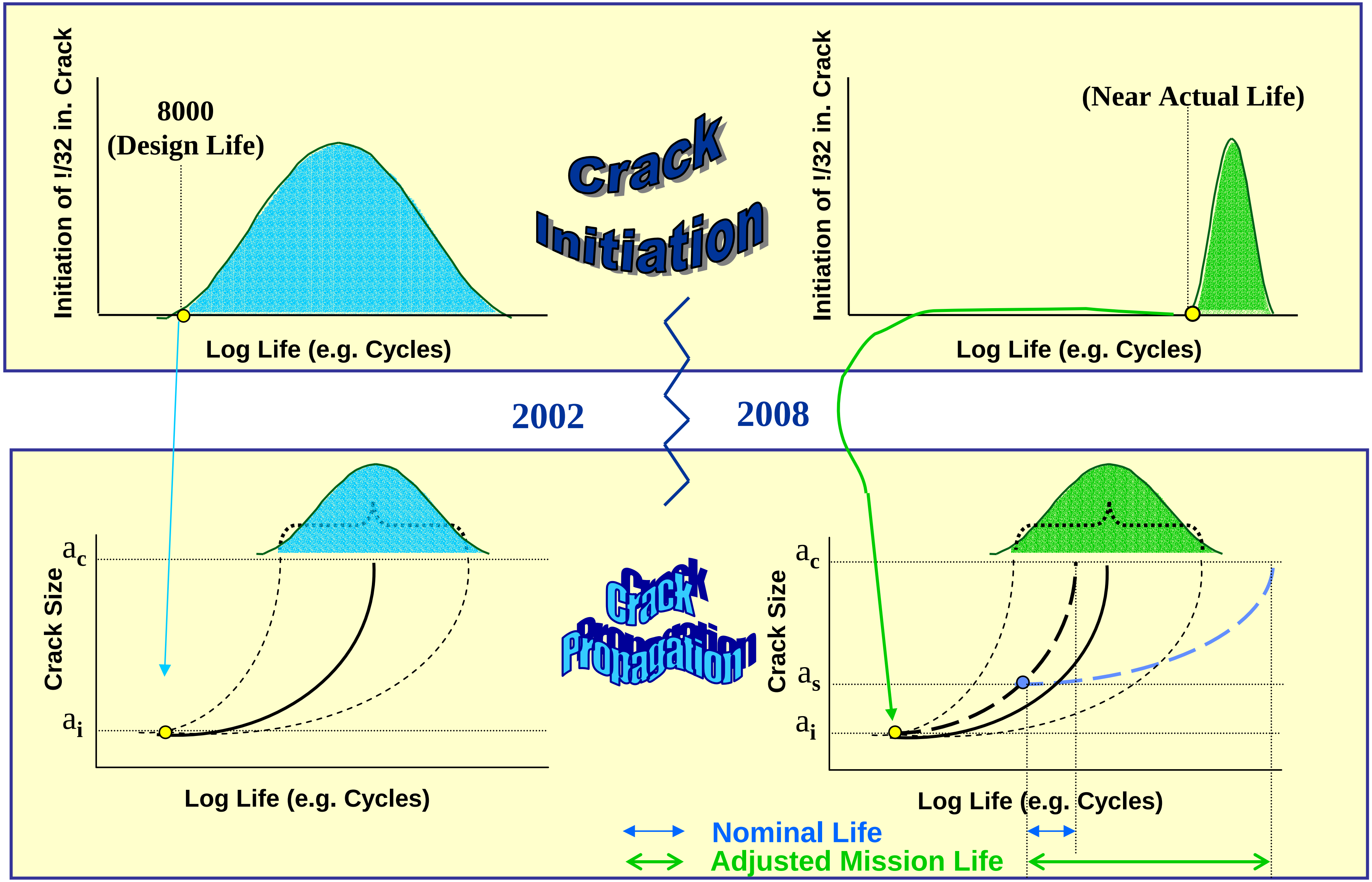
Vision: Materials Damage Prognosis for Turbine Engines

VISION: Develop tools for a reliable, robust, quantitative, integrated life assessment and management system using physics-based models enhanced by information from state-awareness sensors

Key science and technology disciplines

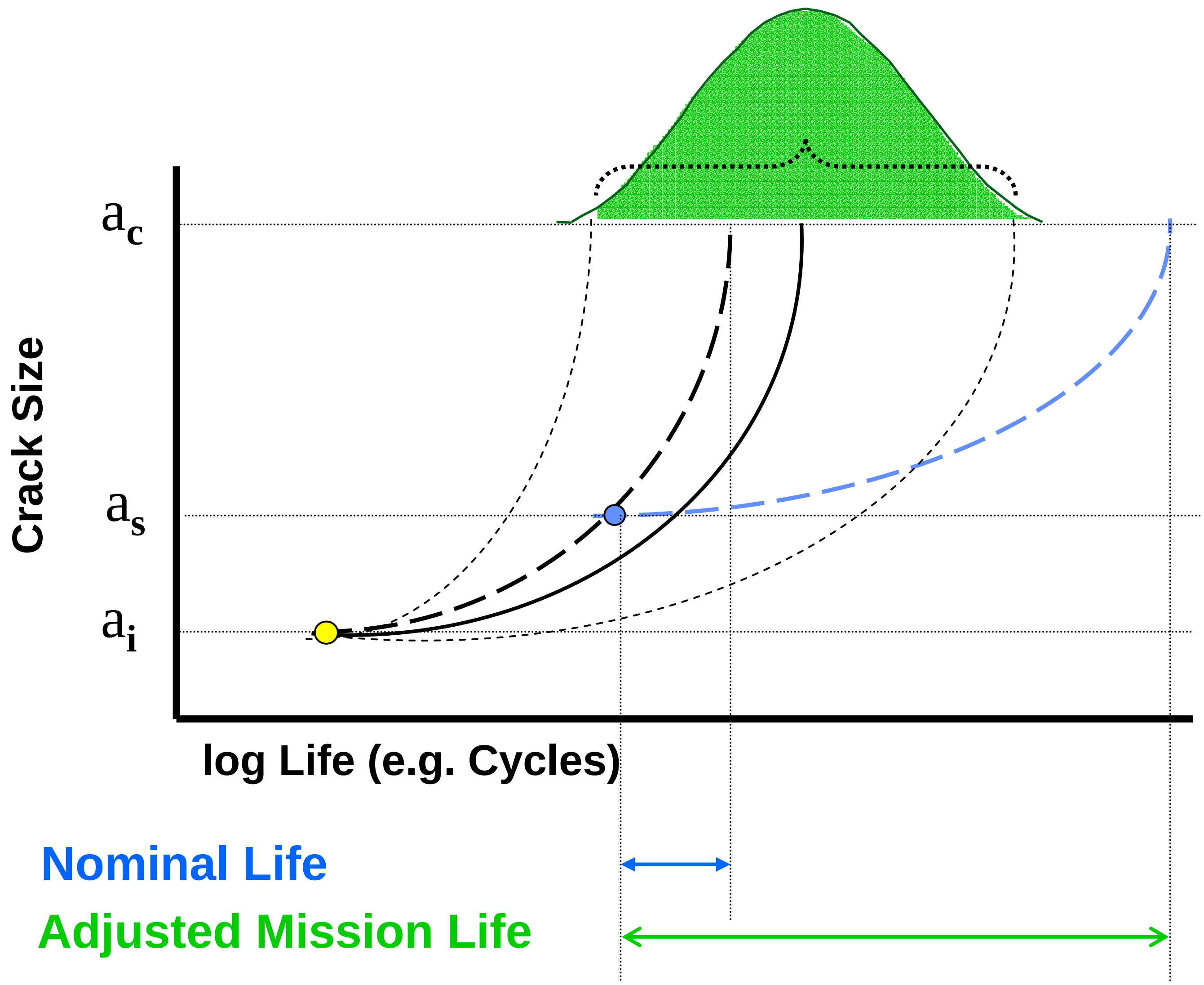
- **Coupled physics-based models of materials damage and behavior**
  - Interaction of multiple damage/failure mechanisms
  - Multi-scale, mechanism-based
  - Microstructurally-based stochastic behavior
  - Integrated information from state-awareness tools
- **Interrogation of damage-state**
  - Intelligently exploit existing sensors
  - Feature extraction from global sensors
  - Materials-damage-state interrogation techniques and recorders
- **Data management and fusion**
  - Component history and pedigree
  - Component usage data
  - Capability matched to mission

Benefits of Prognosis for Turbine Engines



Benefits of Prognosis for Turbine Engines

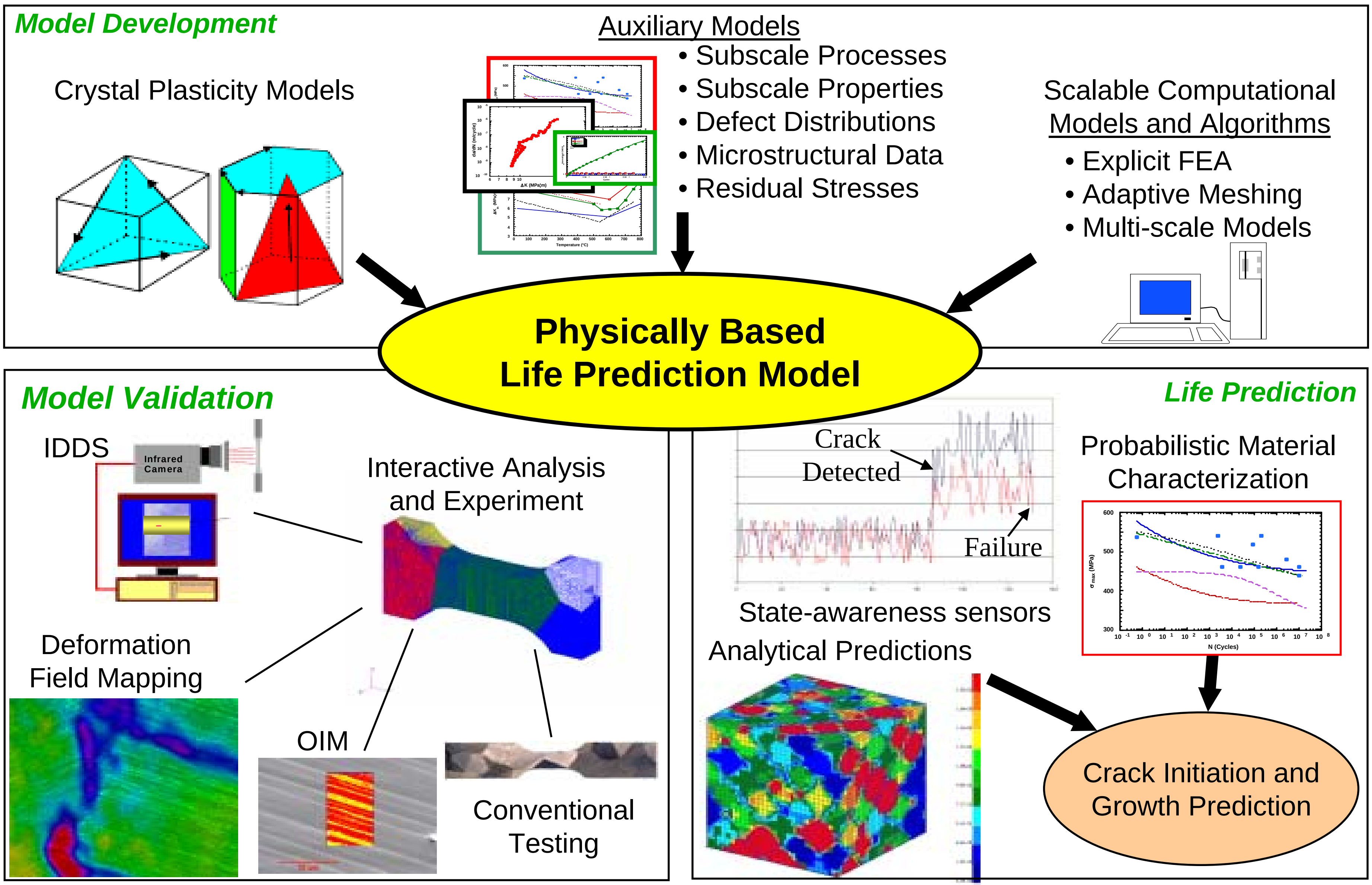
Crack Propagation



Nominal Life

Adjusted Mission Life

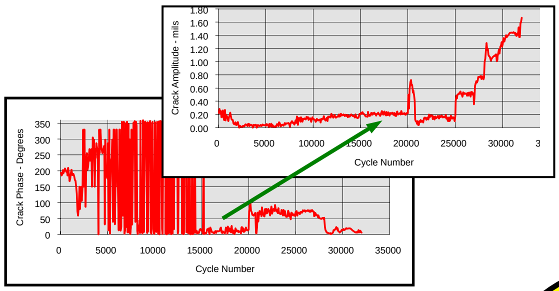
Physics of Failure



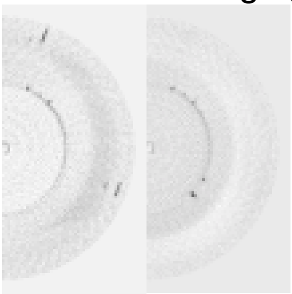
Interrogation Techniques

Crack Detection

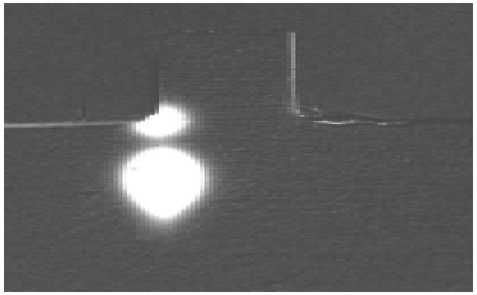
In-situ Monitoring



Whole-field Imaging

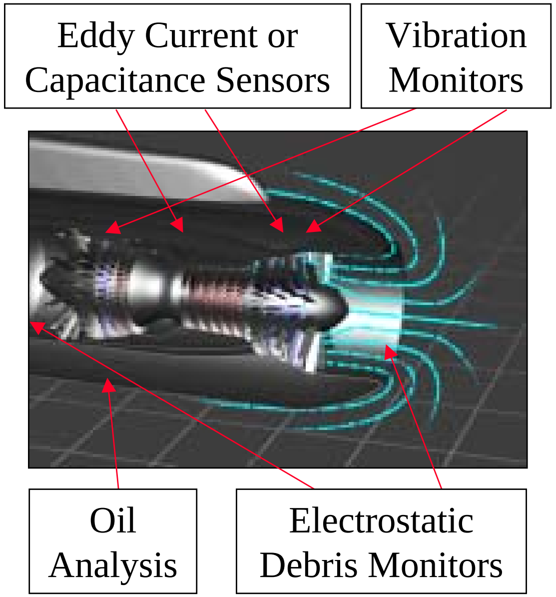


Off-line Inspections

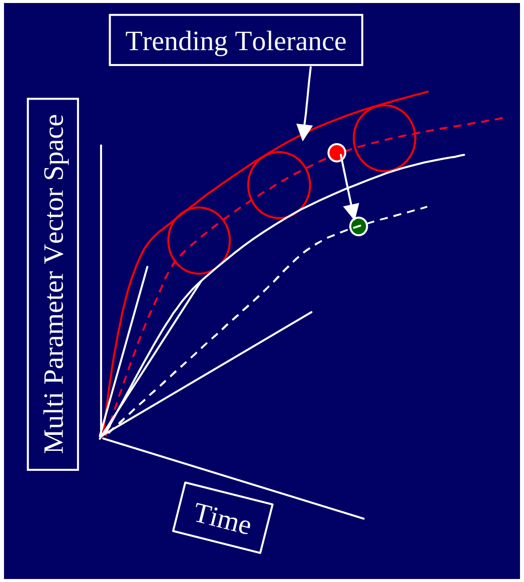


State-Awareness Interrogation

Holistic Monitoring

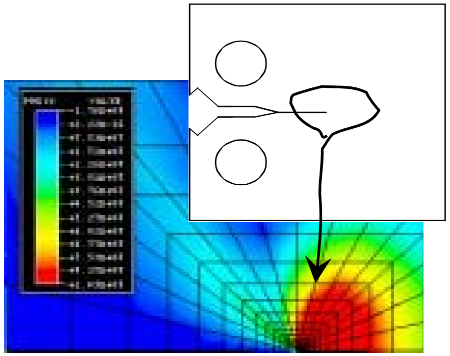


Engine Parameter Trending

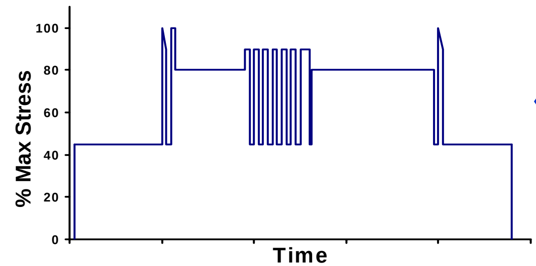


- Metal Temperatures
- Rotational Speeds
- Pressures
- Other ...

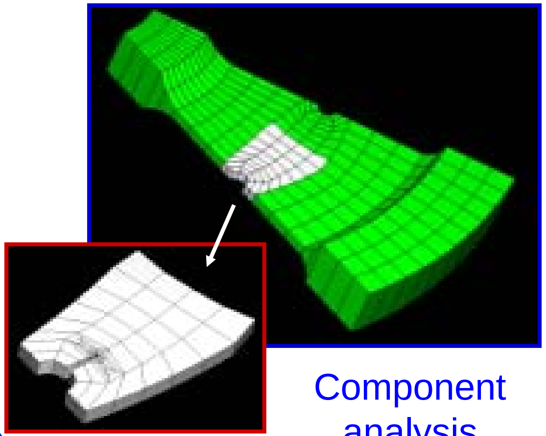
Component Damage Assessment and Prediction



Laboratory specimen experiment & analysis

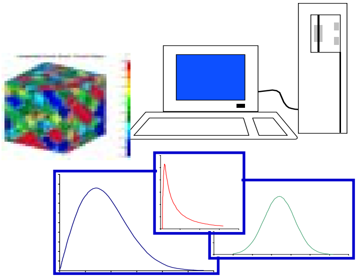


Effect of mission loading

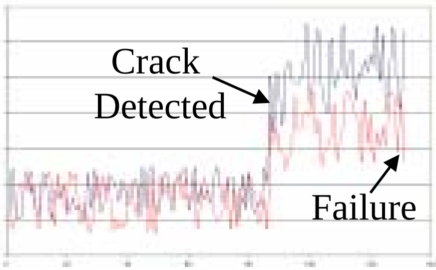


Component analysis

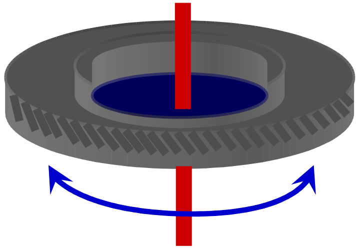
Field experience



Physics-based
Life Prediction Models
(incorporating state-awareness input & probabilistic tools)

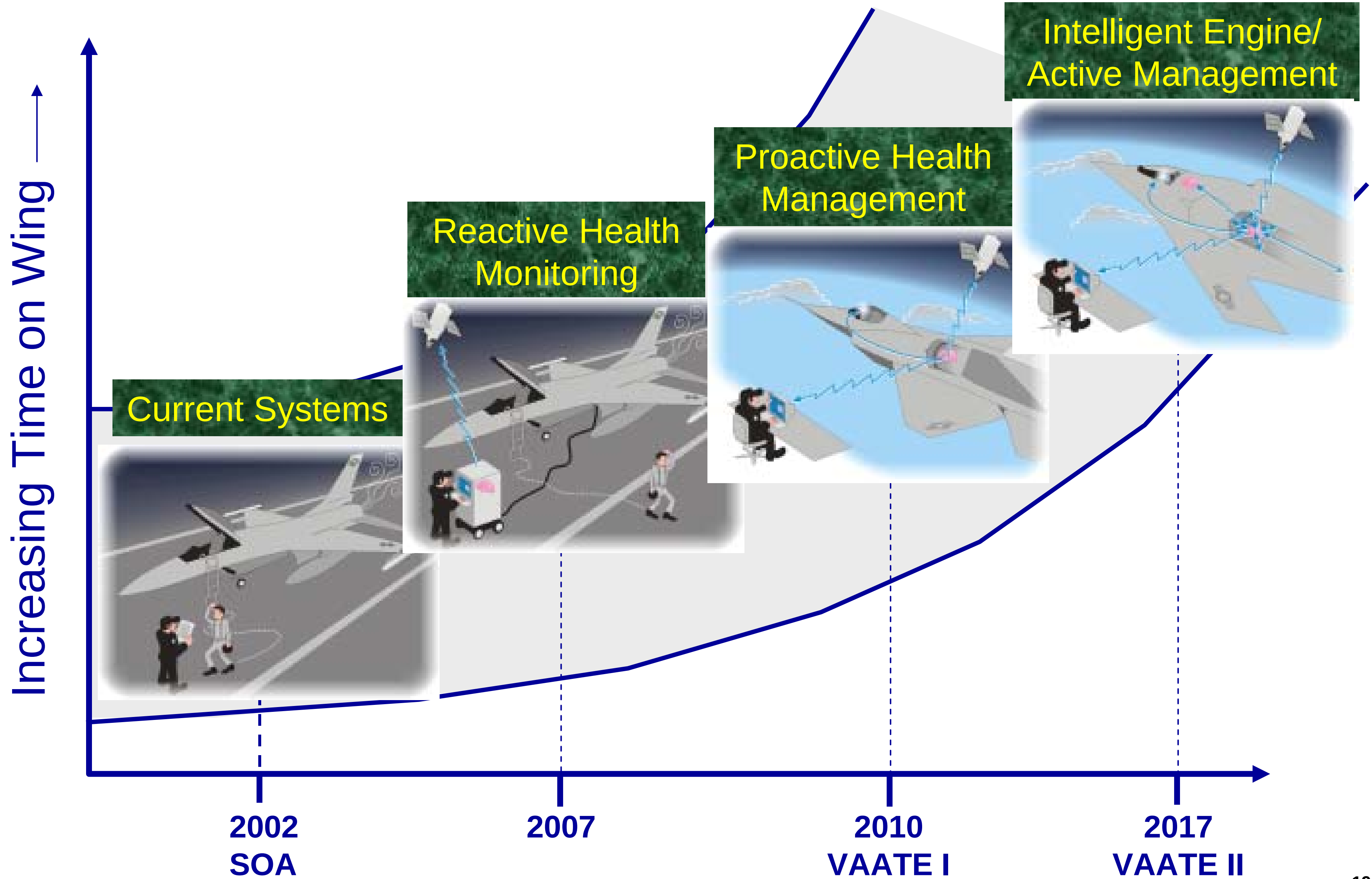


State-awareness sensors



Component demonstrations

Engine Health Management Time-Phased Descriptors



Turbine Engine Science and Technology Plan
Tri-Service/NASA/Industry Coordinated

***Integrated High Performance Turbine Engine Technology (IHPTET)…*Constant Life (F119)**

- 2X Propulsion Capability
  - +100% Engine Thrust/Weight
  - -40% Fuel Burn
  - -35% Production & Maintenance Cost
- National HCF S&T Program

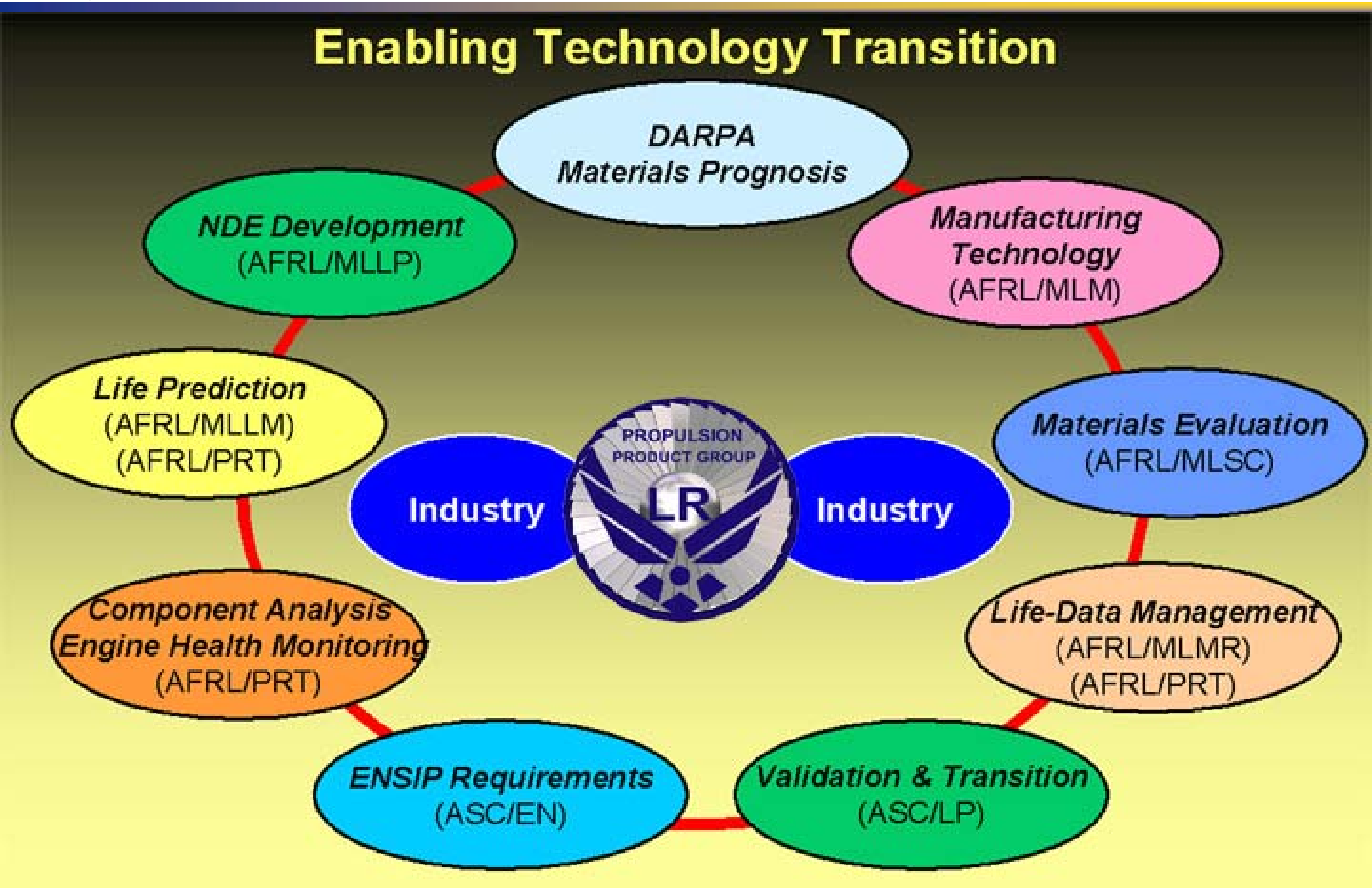
Versatile, Affordable, Advanced Turbine Engines

TODAY

- 10X Propulsion Affordability (Capability / Cost)
  - National Durability Program
  - Maintenance Friendly Versatile Core
  - Ultra-Intelligent Adaptive Engine
- Environmental Efficiencies
- Dev/Prod/Maint Cost Reduction Focus

1987 2002 2005 2017

Engine Life Management



Transition to Service

"The Materials Prognosis Program has huge potential for us in the propulsion community, both today with our legacy engines, and for the future engines like JSF, as well as those which will be derived from the AFRL VAATE initiative."

Mr. Timothy Dues, SES
Manager, Propulsion Product Group
U.S. Air Force
17 September 2002

"Materials Prognosis: Integrating Damage-State Awareness and Mechanism-Based Prediction"

San Diego, California, USA, March 2-6, 2003

In conjunction with the 132nd Annual Meeting & Exhibition of TMS

Sponsored by: Structural Materials Division

Program Organizers:
James M. Larsen: Air Force Research Laboratory - 937-255-1357
Leo Christodoulou: Defense Advanced Research Agency - 703-696-2374
J. William Hardman: Naval Air Systems Command - 301-757-0508
Andrew Hess: Naval Air Systems Command - 703-604-6033, ext. 223
J. Wayne Jones: University of Michigan - 734-764-7503
Stephan M. Russ: Air Force Research Laboratory - 937-255-1356

Scope: **This symposium is intended highlight scientific tools and approaches for development of a comprehensive damage prognosis technology for materials. The objective of such a prognosis capability is to enable continual assessment and prediction of the current and future health of materials in a complex mechanical system or subsystem, such as a turbine engine, helicopter gearbox, or aircraft. The ultimate goal is the development of quantitative models that relate a system's-level structural response to material's-level microstructural events.**

Areas of emphasis include:
(1) methods for in situ interrogation of the damage state of a material, such as that from fatigue and/or creep,
(2) physically-based models of the formation and growth of material damage under realistic loading, and
(3) coupled state-awareness and life models, including probabilistic and uncertainty approaches. The symposium is expected to attract participants from diverse but interdependent disciplines including materials science, mechanical engineering, physics, and diagnostic state-awareness engineering

General John Jumper
Chief of Staff, USAF

General John Jumper
Chief of Staff USAF

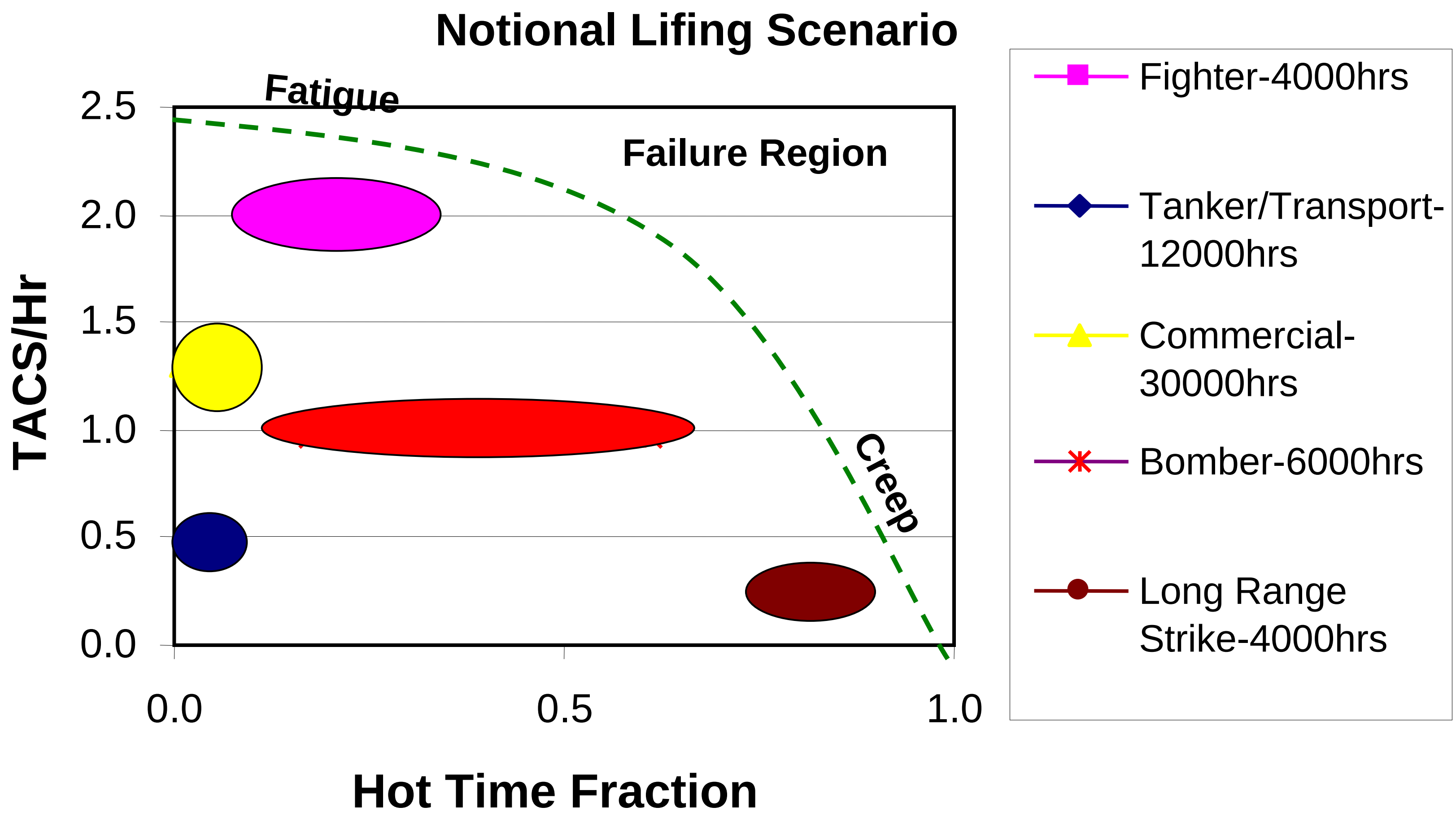
"the two most important things we do: <u>flying and fixing airplanes</u>.

That doesn't mean that you're not important if you're not pulling on a pole in the cockpit or turning a wrench on the flightline. It means that the importance of the rest of us is how we contribute to flying and fixing airplanes."

Source Air Combat Command News Service:
"*Jumper looks back, looks ahead*"
Released: Aug. 30, 2001

Durability Failure Modes

Modes are Mission Dependent



Need a method to compare multi-application life requirements, while maintaining common parts